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SITE RESPONSE FROM ISTANBUL VERTICAL ARRAYS AND STRONG MOTION NETWORK

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ABSTRACT

In the framework of Istanbul Microzonation Project for the European side, the investigated region was divided by a grid system of 250m×250m and site investigations were performed for each cell based on borings and in-situ seismic wave velocity measurements for defining representative soil profiles with shear wave velocity values extending down to the engineering bedrock. Geological and geotechnical laboratory and field testing data with measured seismic wave velocities enabled to determine the engineering properties of the soil and rock layers encountered in all the cells. There have been limited number of earthquakes within 100km range of Istanbul with local magnitude in the range of M_L=4-5 and few more distant and more stronger earthquakes that were recorded by the existing three vertical arrays as well as by the Istanbul Rapid Response Network (IRRN) strong motion stations. Even though the maximum PGA were similar, the observed spectral response were different indicating the importance of the distance and source magnitude concerning the frequency content and predominant soil period ranges. Even though the level of ground shaking intensity is relatively low, efforts were made to evaluate the variation of the recorded accelerations with depth in vertical arrays located at Ataköy, Zeytinburnu and Fatih. Attempts were also made to model the recorded acceleration time histories at the triggered IRRN stations using the acceleration records obtained at the bedrock level from the vertical array stations in the case of the recent 19.5.2011 M_w=5.7 Kütahya earthquake that took place approximately 185km away.

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Site Response From Istanbul Vertical Arrays And Strong Motion Network

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ABSTRACT

In the framework of Istanbul Microzonation Project for the European side, the investigated region was divided by a grid system of 250m×250m and site investigations were performed for each cell based on borings and in-situ seismic wave velocity measurements for defining representative soil profiles with shear wave velocity values extending down to the engineering bedrock. Geological and geotechnical laboratory and field testing data with measured seismic wave velocities enabled to determine the engineering properties of the soil and rock layers encountered in all the cells. There have been limited number of earthquakes within 100km range of Istanbul with local magnitude in the range of M_L=4-5 and few more distant and more stronger earthquakes that were recorded by the existing three vertical arrays as well as by the Istanbul Rapid Response Network (IRRN) strong motion stations. Even though the maximum PGA were similar, the observed spectral response were different indicating the importance of the distance and source magnitude concerning the frequency content and predominant soil period ranges. Even though the level of ground shaking intensity is relatively low, efforts were made to evaluate the variation of the recorded accelerations with depth in vertical arrays located at Ataköy, Zeytinburnu and Fatih. Attempts were also made to model the recorded acceleration time histories at the triggered IRRN stations using the acceleration records obtained at the bedrock level from the vertical array stations in the case of the recent 19.5.2011 Mw=5.7 Kütahya earthquake that took place approximately 185km away.

Introduction

The first stage of the Istanbul Microzonation Project involved detailed microzonation studies that were conducted on the European side of the city [1]. The investigated region was divided by a grid system into cells of 250m×250m and detailed site investigations were conducted in each cell based on borings and in-situ measured seismic wave velocities for defining representative soil profiles with shear wave velocity values extending down to the engineering bedrock [2].

The Istanbul Rapid Response Network (IRRN) composed of strong motion stations distributed more or less evenly with the metropolitan city of Istanbul. 55 of these strong motion stations are located within the area where detailed microzonation study was conducted [3]. In

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addition three vertical arrays were installed in the same area at Ataköy, Zeytinburnu and Fatih extending all the way down to the engineering bedrock (V_s > 750m/s) as in Figure 1 [4,5,6,7,8].

There have been limited number of earthquakes within 100km range of Istanbul with local magnitude in the range of M_L=4-5 and few more distant and more stronger earthquakes that were recorded by the existing three vertical arrays as well as by the Istanbul Rapid Response Network (IRRN) strong motion stations. The stations that recorded the evaluated two events Cınarcık and Kütahya earthquakes are also shown in Figure 1.

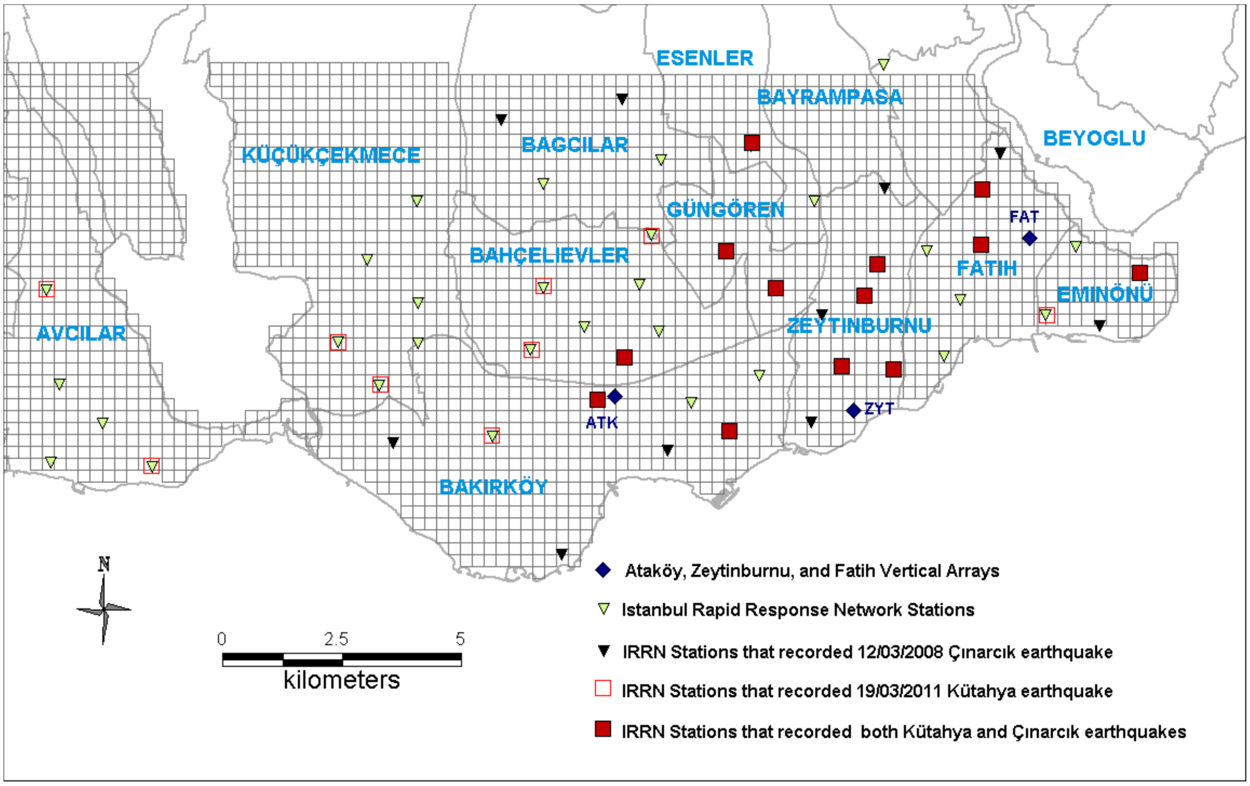

Figure 1. The distribution of IRRN strong motion stations and the locations of the three vertical arrays within the detailed microzonation area on the European side of Istanbul.

Çınarcık and Kütahya Earthquakes

During the recent years, Istanbul has experienced limited amount of minor earthquakes. Among these, the highest peak ground accelerations were produced by the M_L=4.8 Çınarcık earthquake that took place on 12/03/2008. It was a shallow event with focal depth about 11km, generated by strike-slip movement of one segment of the North Anatolian Fault in the Marmara Region. On the other hand, the M_w=5.7 Kutahya Earthquake of 19.5.2011 were the strongest but distant earthquake recorded by the three vertical arrays. The epicenter distances for these two events were significantly different, Cinarcık epicenter was about 43km while the Kutahya epicenter was about 205km away. As a result as shown in Figure 2, the predominant periods based on acceleration spectra for these two events recorded by the Atakoy vertical array were significantly different due to the differences in the triggering dominant wave frequencies. These two events, even though the PGA at the bedrock level was very similar, in the range of 7mg, indicate that the frequency content and predominant site periods can be significantly different even at the same level of ground shaking and thus is controlled mainly by the source distance and magnitude rather than local site conditions. The effect of distance has introduced differences not in the recorded peak ground accelerations but rather in the frequency content of the acceleration time history and thus in elastic acceleration response spectra as shown in Figure 2.

This observation indicates the importance of distance resulting in filtering the higher frequency content of the earthquake ground motion. Thus the definition of predominant periods based on near field small earthquakes and noise measurements may be questionable with respect to the definition of predominant soil periods. The predominant soil periods are very dependent on input ground motion characteristics and thus the use of noise measurements may not always give reliable results with respect to the effects of local site conditions.

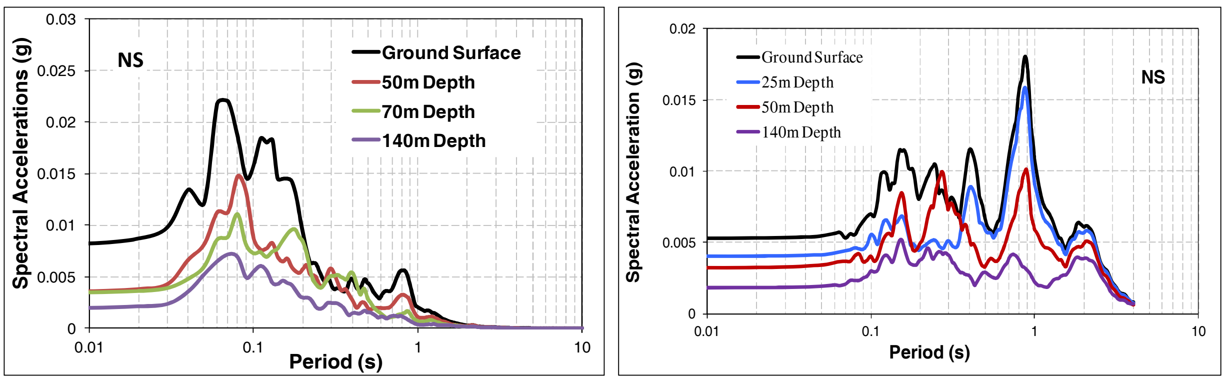

Figure 2. Acceleration response spectra at different depths for (a) M_L=4.8 Çınarcık Earthquake of 12.3.2008 (b) M_w=5.7 Kütahya Earthquake of 19.3.2011 at Ataköy Vertical array.

The M_w=5.7 Kütahya Earthquake of 19.5.2011 was the first event that is recorded by all three vertical arrays. Even though the measured shear wave velocities at the deepest part of these three arrays were in the range of 1000m/s, and the distance between these arrays are in the range of 5-10km, the frequency characteristics of the recorded acceleration time histories were significantly different with respect to EW and NS components as shown in Figure 3. This indicates the importance of the geological characteristics of the engineering bedrock formations. In the case of NS components, engineering bedrock acceleration spectra are similar for Zeytinburnu and Fatih vertical arrays which are on the same geological formation.

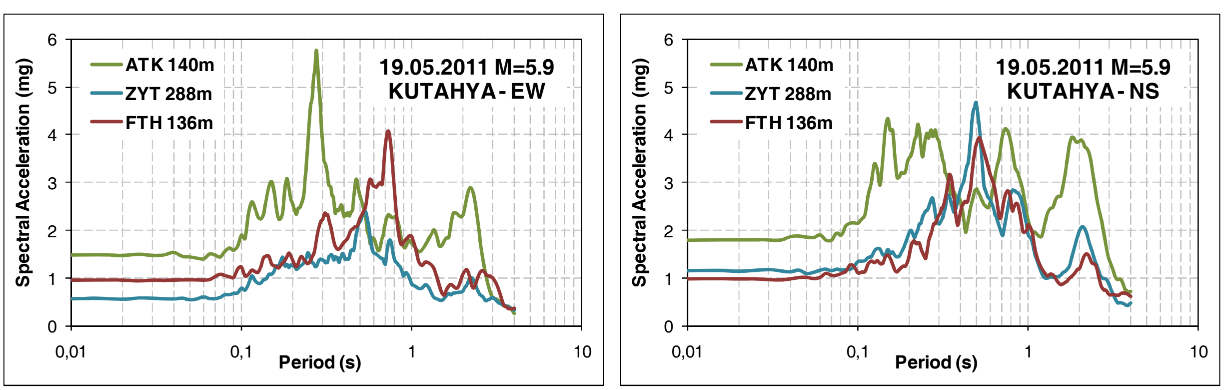

Figure 3. Acceleration response spectra of the recorded motion at the bedrock level for the three vertical arrays during the M_w=5.7 Kütahya Earthquake of 19.5.2011.

Variation of Earthquake Characteristics with Depth

The effect of directional differences may be observed in the acceleration spectra calculated at different levels of the Fatih vertical array during M_w=5.7 Kütahya Earthquake of 19.5.2011 as shown in Figure 4. At the bedrock level (-136m), PGA in both directions were in the order of 1mg and the elastic acceleration response spectra in EW and NS directions were very similar. However, as the PGA increases to 11mg in NS direction and to 7.6mg in EW direction on the ground surface, the acceleration spectra becomes significantly different. One possible reason for this observed variation with direction within the soil layers is the anisotropic properties of the soil layers that even under relatively low level of shaking intensity may lead to different response patterns with recording direction.

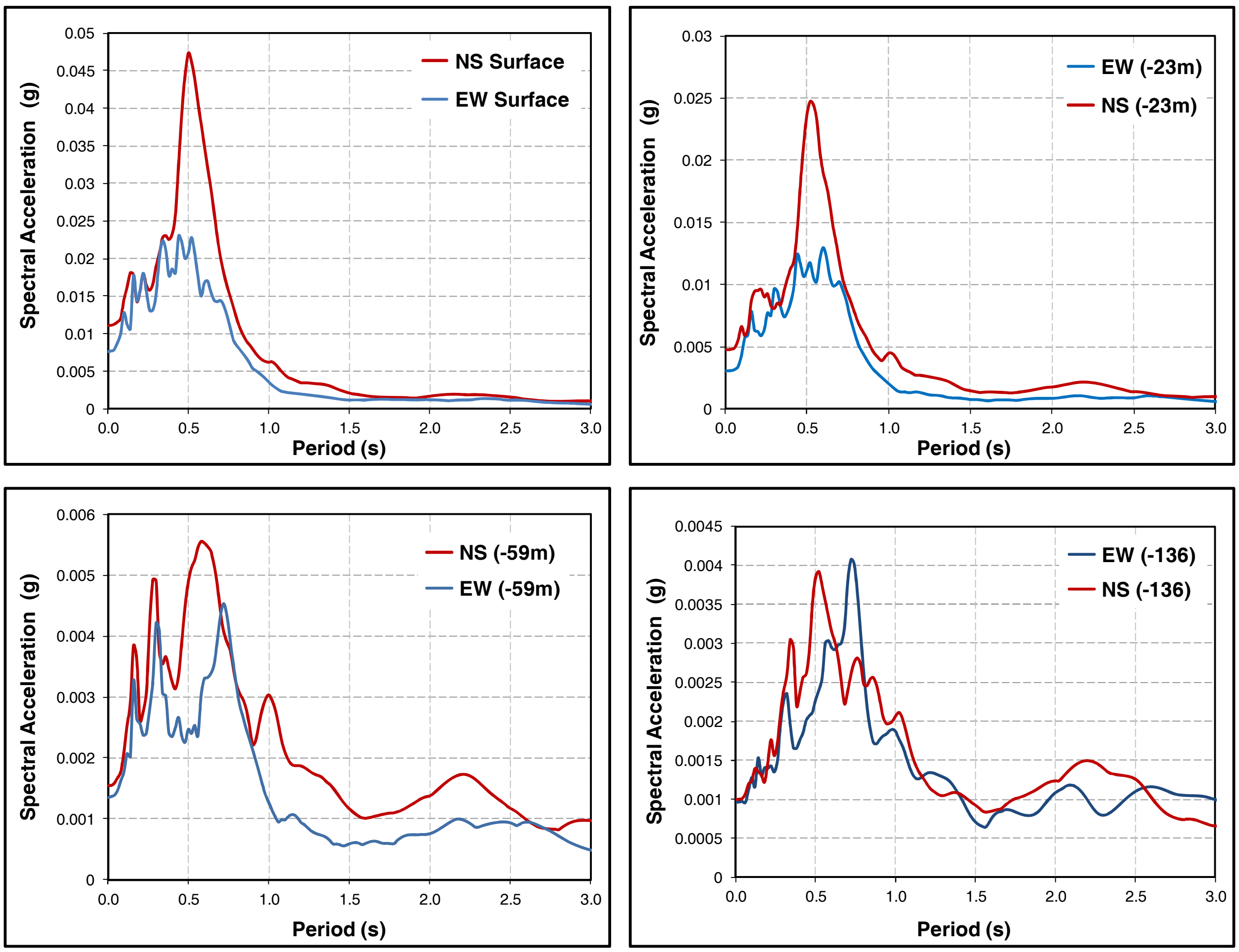

Figure 4. Acceleration response spectra at four levels of the Fatih vertical array during the M_w=5.7 Kütahya Earthquake of 19.5.2011.

Similar response pattern were also observed in the Fatih vertical array during the M_L=5.1 Marmara Sea earthquake with epicenter distance of 88 km as shown in Figure 5. The acceleration response spectra with respect spectral acceleration levels are very similar in EW and NS direction even at -59m level, however, becomes significantly different at -23m and on the ground surface. Even though the PGA level on the bedrock level (-134m) were almost same approximately 0.2mg that increases to 3mg in EW and 2mg in NS directions on the ground surface. It is also interesting to observe unlike what is observe in Figure 4 where predominant period do not change with respect to direction, the predominant period in the EW direction moves to 0.45s while in the NS direction it is still in the 0.15s as observed in the bedrock level.

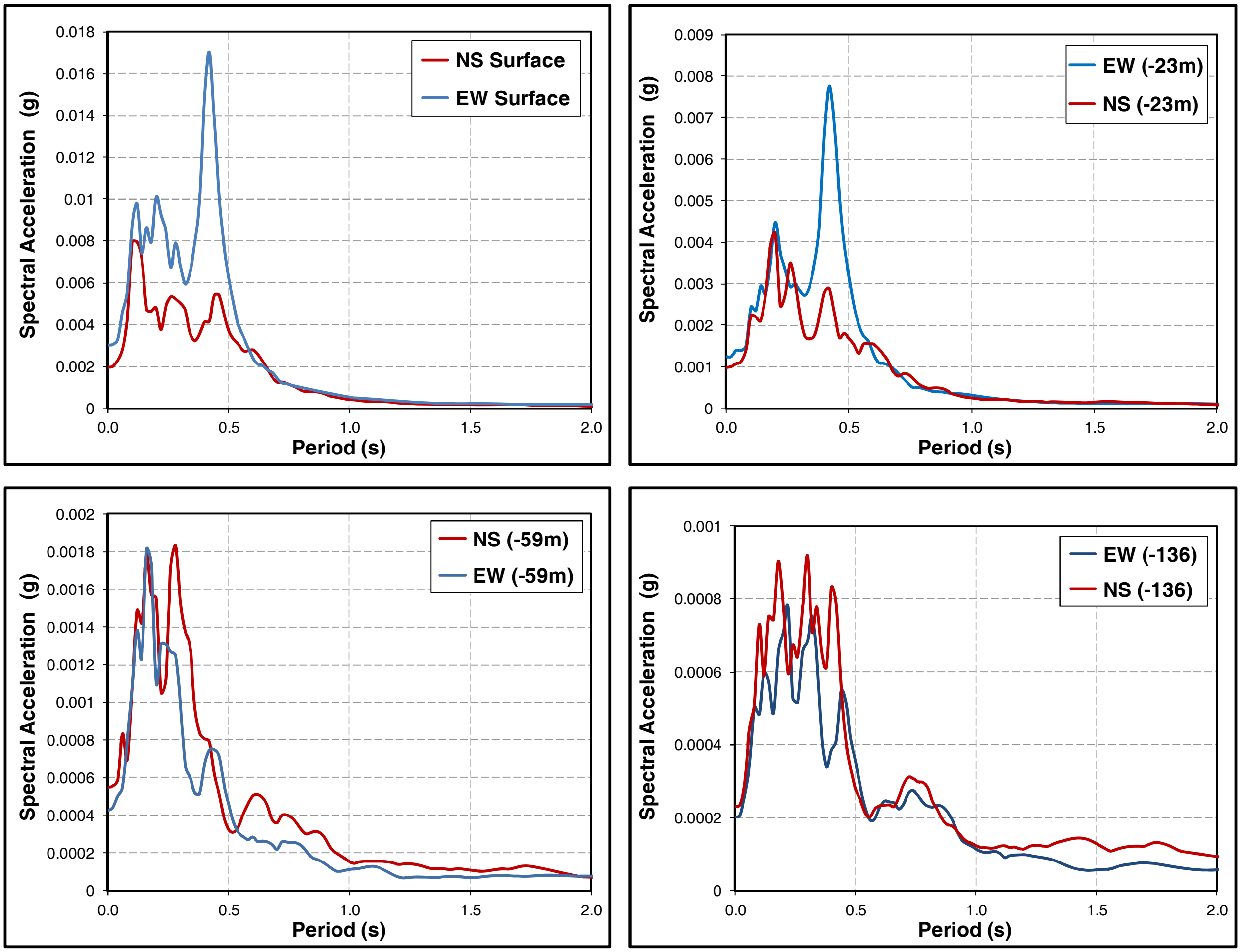

Figure 5. Acceleration response spectra at four levels of the Fatih vertical array during the M_L=5.1 Marmara Sea of 7.6.2012.

Büyükçekmece Istanbul Earthquake

Among the recorded ground motions, the closest epicenter distance (on the average of 25km to all vertical arrays) was for the 19.10.2012 M_L=3.8 Büyükçekmece earthquake. It was interesting to observe that the records obtained in EW and NS directions were very similar with respect to acceleration spectra at all levels of the Zeytinburnu vertical array as shown in Figure 6. One possible explanation is the very low level of shaking intensity during this near field earthquake where the recorded PGA on the bedrock was 1mg that increases to 2mg in EW and 2.5mg in NS directions. Considering the 288 m thickness of soil deposit at the Zeytinburnu vertical array the amplification is very low indicating almost totally elastic response. However, in the case of Fatih vertical array for the same earthquake the spectral accelerations obtained at all four levels were significantly different in EW and NS directions as shown in Figure 7.

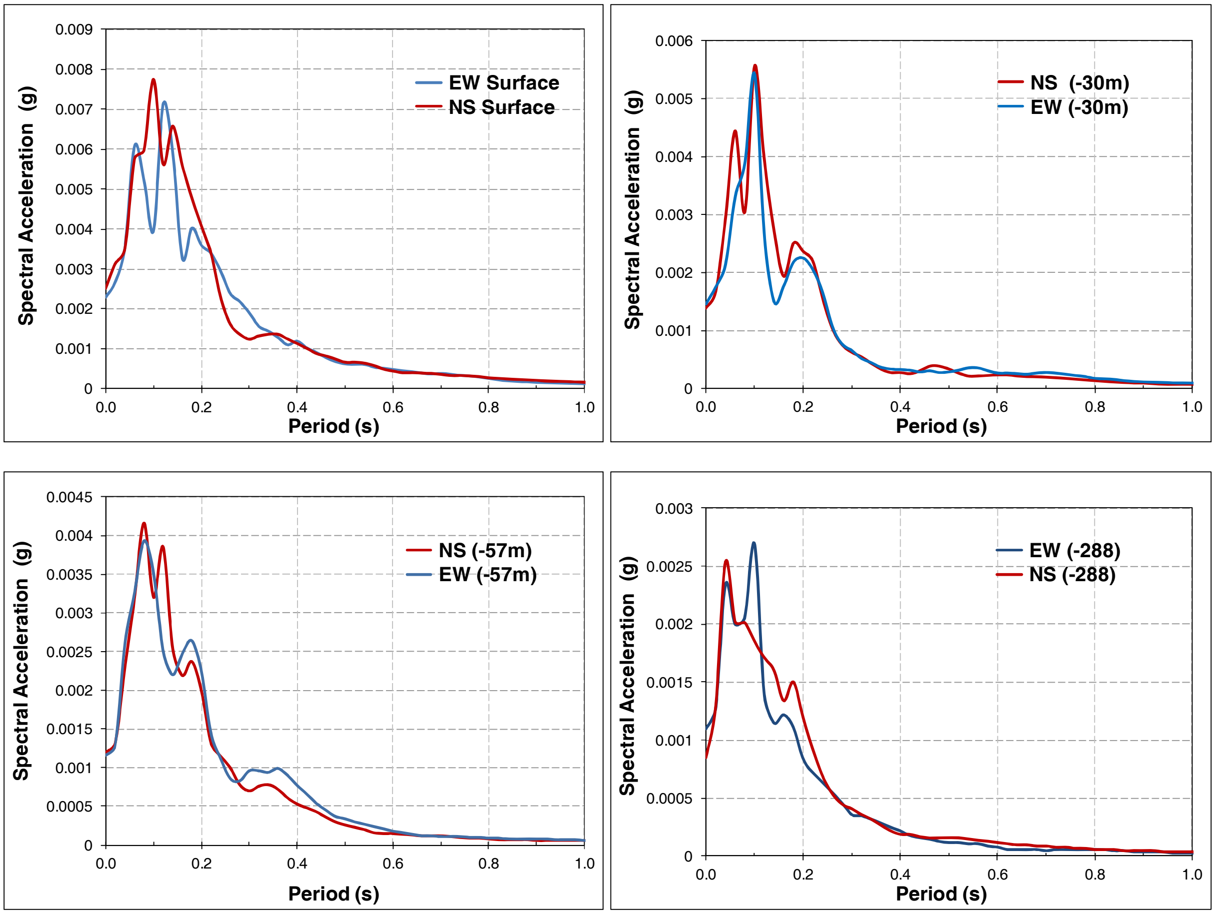

Figure 6. Acceleration response spectra at four levels of the Zeytinburnu vertical array during the M_L=3.8 Büyükçekmece Earthquake of 19.10.2012.

Modeling site Response

There are two alternatives in modeling the observed earthquake characteristics on the ground surface. One option is to adopt an empirical approach based on amplification factors such as suggested by Borcherdt [9] even though the excitation level is very low and not within the suggested range of bedrock excitations. In this case the site conditions are defined with respect average (equivalent) shear wave velocity for the top 30m for each station based on the borings conducted in the near vicinity of the stations as shown in Figure 8. It can be easily demonstrated based on these limited differences in the average shear wave velocities, the peak ground acceleration will not be very different on the ground surface, contrary to what has been observed. One reason for larger differences in the peak ground accelerations can be the differences of the engineering bedrock depths as shown in Figure 9.

The second option is to use site response analyses using the bedrock motion recorded at the vertical arrays. Considering the observed variation of the recorded acceleration time histories at the engineering bedrock levels, site specific earthquake characteristics on the ground surface for the 20 IRRN stations were calculated using Shake91 [10] one dimensional, equivalent linear site response code for the three acceleration time histories recorded in all three vertical arrays as shown in Figure 10.

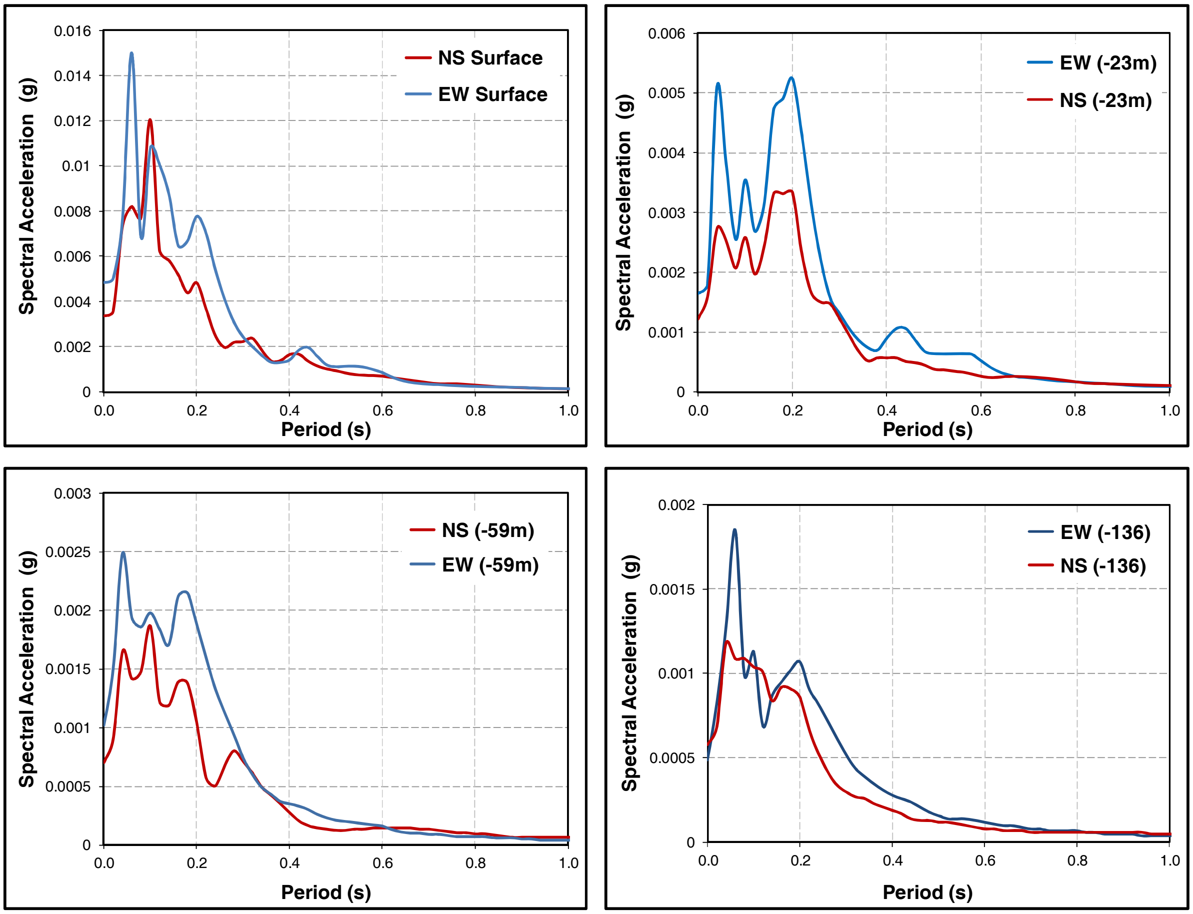

Figure 7. Acceleration response spectra at four levels of the Fatih vertical array during the M_L=3.8 Büyükçekmece Earthquake of 19.10.2012.

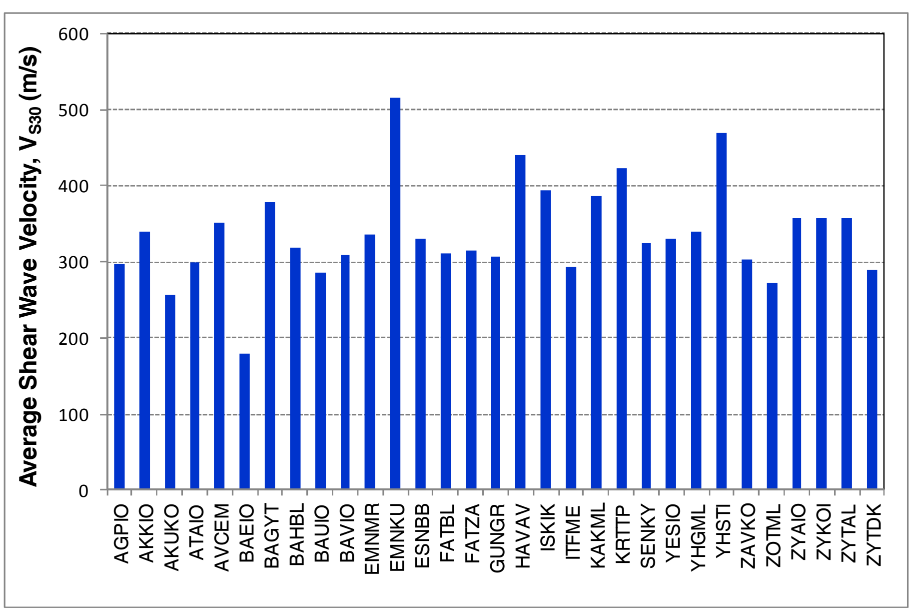

Figure 8. Average Shear Wave Velocity for the 20 IRRN strong motion stations that recorded M_w=5.7 Kutahya Earthquake

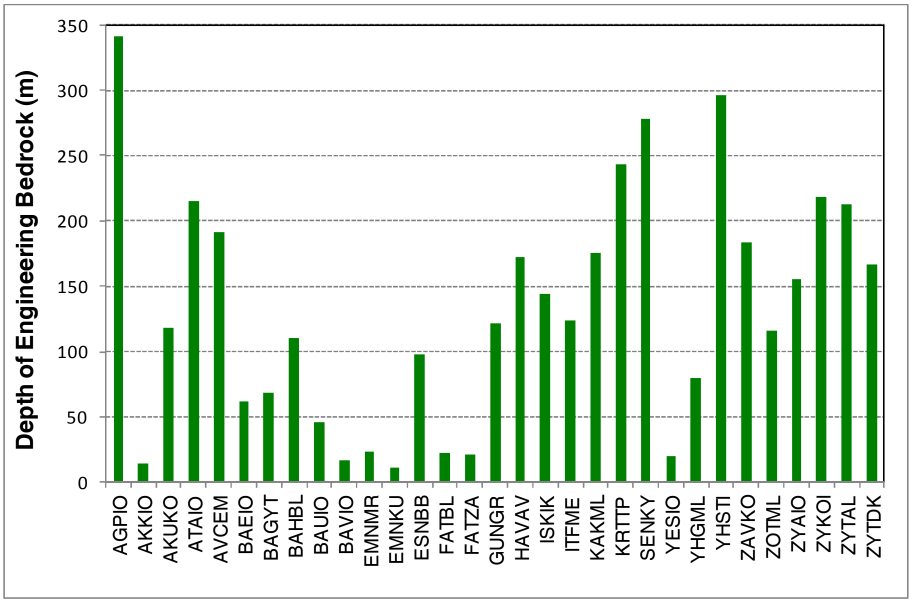

Figure 9. Depth of engineering bedrock for the 20 IRRN strong motion stations that recorded M_w=5.7 Kutahya Earthquake

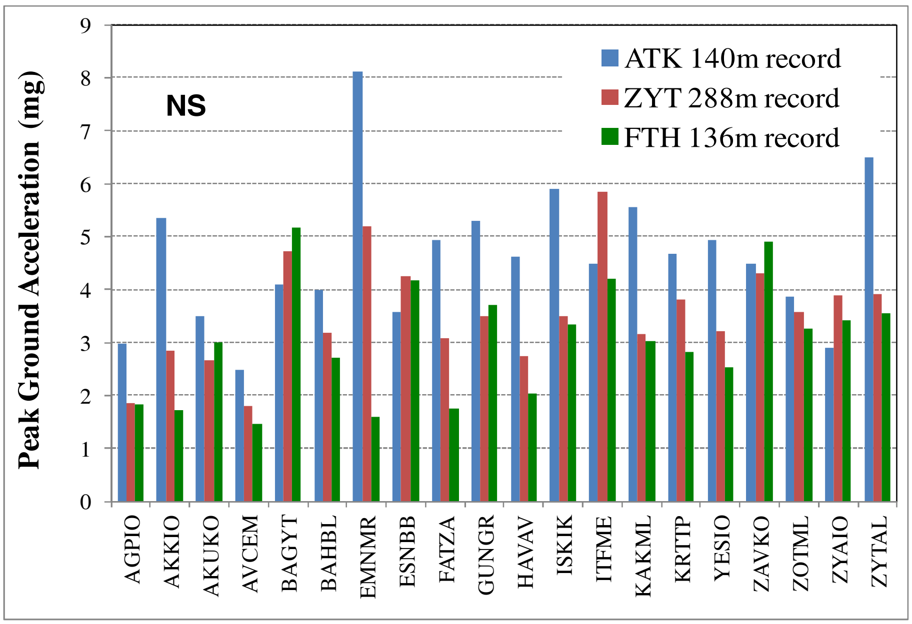

Figure 10. Calculated peak ground acceleration for 20 IRRN strong motion stations using the recorded bedrock acceleration at the three vertical arrays during M_w=5.7 Kütahya Earthquake

One possibility to compare the observed and calculated peak ground acceleration is to determine the best fit with respect to the three site response result obtained using the recorded acceleration time histories at the engineering bedrock level for the three vertical arrays. The comparison between the calculated and observed obtained is almost perfect match as shown in Figure 11. This preliminary exercise clearly demonstrates the suitability for estimating the earthquake characteristics on the ground surface by site response analysis rather than by another approach.

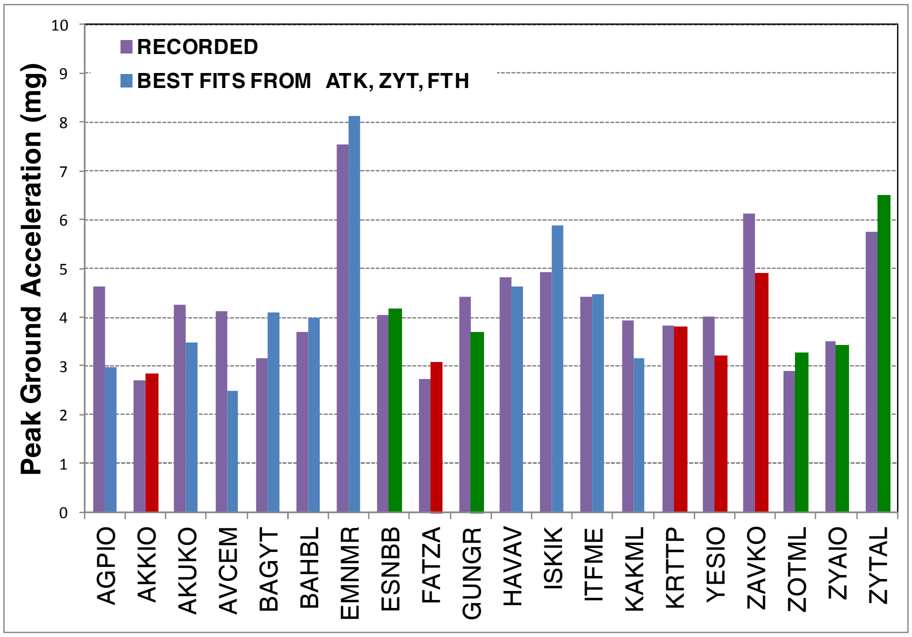

Figure 11. Comparison of best fits calculated and recorded peak ground accelerations for M_w=5.7 Kutahya Earthquake at 20 stations that recorded the event.

Conclusions

Three geotechnical vertical arrays were recently installed in the European Side of Istanbul. Data recorded so far at these vertical arrays represent low amplitude motions which induced more or less linear soil response. Based on the recorded acceleration records, it was observed that the magnitude and epicenter distance are two important factors controlling the engineering characteristics of the acceleration time histories along the depth and on the ground surface. In the case of very low shaking intensity the site response yield purely elastic behavior. However, even in the range of 10mg levels some directional amplification effects are observed in the recorded acceleration time histories with respect to elastic acceleration spectra.

Data from these arrays also provide reference bedrock motion for the strong motion network that is in operation at the European side of Istanbul. Investigation of ground motions recorded at 20 IRRN stations for both Çınarcık and Kütahya earthquakes with significantly different epicenter distances demonstrates that V_{s30} may be a poor indicator of site amplification potential. Comparisons of the recorded and predicted behavior at these stations suggest that the observed response can be modeled by 1D site response analyses using detailed site profiles.

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References

1. OYO, Inc. Production of Microzonation Report and Maps – European Side (South), Report for Istanbul Metropolitan Municipality Microzonation Project, 2007
2. Ansal A, Kurtuluş A, Tönük G. Seismic microzonation and earthquake damage scenarios for urban areas. *Soil Dynamics and Earthquake Engineering* 2010, 30:1319-1328
3. Erdik M, Fahjan Y, Özel O, Alcik H, Mert M, and Gül M. Istanbul Earthquake Rapid Response and the Early Warning System. *Bulletin of Earthquake Engineering* 2003; 1(1):157-163
4. Ansal A, Tönük G, Kurtuluş A, Erdik M, Parolai S. Modeling The Observed Site Response From Istanbul Strong Motion Network. *Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*, San Diego, CA - May 24-29, 2010
5. Kurtulus A. Istanbul Geotechnical Downhole Arrays, *Bulletin of Earthquake Engineering*, 9 (5):1443-1461, 2011
6. Kurtuluş A, Ansal A, Şafak E. Geotechnical Arrays Recently Deployed in Istanbul. *Proceedings of 4th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion*, Santa Barbara, USA, 24-25 August 2011
7. Parolai s, Ansal A, Kurtulus A, Strollo A, Wang R, Zschau J. The Atakoy vertical array (Turkey): Insights into seismic wave propagation in the shallow-most crustal layers by waveform deconvolution. *Geophysical Journal International*, 178 (3):1649-1662, 2009
8. Parolai S, Bindi D, Ansal A, Kurtulus A, Strollo A, Zschau J. Determination of shallow S-wave attenuation by down-hole waveform deconvolution: a case study in Istanbul (Turkey), *Geophysical Journal International*, 181 (2): 1147–1158, 2010
9. Borcherdt RD. Estimates of Site Dependent Response Spectra for Design (Methodology and Justification). *Earthquake Spectra*. 10(4): 617-654.1994
10. Idriss, I. M. and Sun J. I.: Shake91, *A Computer Program for Conducting Equivalent Linear Seismic Response Analysis of Horizontally Layered Soil Deposits*, Modified based on the original SHAKE program by Schnabel, Lysmer and Seed, 1972, 1992